



Environmental and Safety Designs, Inc.

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March 5, 1992

Ms. Beth Brown
Remedial Project Manager
KY/TN Unit, NSMS
Superfund Branch
U.S. Environmental Protection Agency
345 Courtland St.
Atlanta, GA 30365

Subject: Collierville Site: Soils Remediation Criteria for Groundwater Protection

Dear Beth:

This letter formally transmits the results of our revised calculations and MULTIMED modeling of soil contamination at the subject site. The resulting threshold for source area soils TCE contamination that will be protective of the Memphis Sands is 533 $\mu\text{g/kg}$. For clarity, the calculations for vadose zone percolate volumes have been typed. The entire soils clean-up criteria calculation section, as it will appear in an Appendix to the Baseline Risk Assessment, is enclosed.

Best Regards,

Craig A. Wise
Chemical Engineer

copy:

Nelson Wong,
Gerald Bailey,
Art Kanerviko,
Carl Krull, CAC;
Phil Coop,
Ted Blahnik, EnSafeSM

enclosure



10663357

APPENDIX R

SOIL CLEAN-UP FOR GROUNDWATER PROTECTION CARRIER/COLLIERVILLE SITE

1. General Information

USEPA Center for Environmental Assessment Modeling (CEAM) provided their Exposure Assessment Multimedia Model (MULTIMED) for use in determining soil clean-up levels necessary for protection of groundwater. The MULTIMED model was designed to predict groundwater contaminant concentrations downgradient from landfill based "leachate" concentrations. If acceptable contaminant levels are known for the downgradient groundwater plume, initial acceptable leachate concentrations can be found by MULTIMED through trial and error input. Acceptable leachate concentrations can then be used to derive acceptable soil clean-up levels from contaminant mass balance data and vadose zone characteristics.

2. MULTIMED Application

MULTIMED was applied to estimated and calculated site-specific hydrologic and hydrogeologic conditions in conjunction with contaminant specific physical and chemical parameters. Site data was entered into four major categories- vadose zone variables, chemical variables, source variables, and aquifer variables.

A. Vadose Zone Variables

The vadose, or unsaturated, zone variables are used by MULTIMED to determine fate and transport of the leachate as it passes through the unsaturated zone at the site. However, leachate concentrations for this site were given at the shallow groundwater surface. As a result, no leachate transport modeling for the unsaturated zone was required in this MULTIMED run.

B. Chemical Specific Variables

Chemical specific variables are used to describe the type of contaminant being modeled. For this site, the contaminant modeled was trichloroethylene. Chemical parameters required by MULTIMED for this site included the normalized distribution coefficient, biodegradation coefficient, molecular weight, mole fraction of solute, vapor pressure, and henry's law constant. Conservative values were used for any unavailable data. Chemical parameters are summarized in Table 1.

Table 1: Chemical Specific Variables

Variable	Units	Value	Source
Reference Temperature	°C	25.0	--
Normalized Distribution Coefficient (K_{oc})	ml/g	126.0	Appendix D, EPA Document 540/2-89/057, October, 1989
Distribution Coefficient (K_d)	--	0.0804	$K_d = K_{oc} * TOC$
Biodegradation Coefficient, Saturated Zone	1/yr	0.0	Most conservative estimate
Molecular Weight	g/mol	131.4	--
Mole Fraction of Solute	--	0.123E-5	--
Vapor Pressure of Solute	mm Hg	74.0	--
Henry's Law Constant	atm-m ³ /mol	0.011	--

C. Source Specific Variables

Source specific variables are used to describe the quality and quantity of contaminant being modeled. Source parameters required by MULTIMED for this site included infiltration rate, spread of contaminant source, recharge rate, initial concentration at landfill, facility length, and facility width. The infiltration rate was based on 35 year rainfall data and water mass balance calculations. Infiltration calculations are provided in Attachment C to this appendix. Source specific variables are listed in Table 2.

The recharge rate is the rate at which groundwater is introduced to the modeled aquifer from an upgradient source. Because recharge contributes to a general dilution of groundwater contamination, a most conservative value of zero recharge was estimated for the recharge rate.

To account for variance in observed groundwater analytical data, a Monte-Carlo statistical method was employed by MULTIMED. The mean (avg) and standard deviation (SD) for shallow groundwater analytical data (initial leachate concentrations) were calculated using a normal distribution for data from wells near the source zone. Wells included were MW-1B, 3, 5, 9, 15, 29, 31, and 35. Initial concentrations were used for a preliminary model run and then reduced until a theoretical downgradient level of approximately 5 ug/l was achieved. The final reduced concentration distribution was then identified as the allowable or "target" leachate concentration.

In the MULTIMED model, the "facility area" is surface area of a source zone through which groundwater travels enroute to the shallow aquifer. Facility area was estimated from unpaved areas of soil contaminant isopleths presented in the Remedial Investigation Report for this site. Using these isopleths, an estimated 20,000 square meters exists as "facility area" at this site.

Table 2: Source Specific Variables

Variable	Units	Value	Source
Infiltration Rate	m/yr	0.157 to 0.45	Water Balance Calculations
Recharge Rate	m/yr	0.0	Assumes no addition of water from upgradient source
Initial Concentration at Landfill (Initial Leachate Concentration)	mg/l	avg = 9.4 min = 0.005 max = 66 S.D. = 21	Normal Distribution calculated from groundwater analytical data
Initial Concentration at Landfill (Target Leachate Concentration, X_{lch})	mg/l	avg = 0.033 min = 0.005 max = 0.24 S.D. = 0.076	Normal Distribution estimated for groundwater clean-up goals
Facility Area	m ²	20000	Estimate from unpaved areas of soil isopleths

D. Aquifer Specific Variables

Aquifer specific variables are used to describe the characteristics of the saturated zone. Aquifer data for the perched zone above the Jackson Clay were derived from field and laboratory testing or estimated from tabulated values for a medium to coarse grain sands with traces of gravel and silt. Aquifer specific variables are summarized in Table 3.

The downgradient receptor well at which theoretical leachate concentrations were calculated was located approximately 100 meters from the source zone and at the surface of the shallow aquifer. This distance requires MULTIMED to calculate the contaminant concentration of the shallow aquifer near the Jackson Clay "pinch-out" where the shallow aquifer first comes into contact with the Memphis Sands Aquifer.

Table 3: Aquifer Specific Variables

Variable	Units	Value	Source
Aquifer Porosity (n)	--	0.35	Estimate for relatively clean sands
Bulk Density (Γ)	g/cc	1.86	Estimate for relatively clean sands
Aquifer Thickness (b)	m	1.0	Estimate from USGS Survey Cross-Sections
Source Thickness (Mixing Zone Depth (H))	m	1.0	$H = (\alpha_v * L)^{1/2} + b * (1 - \exp(-L * Q_f / (V_s * n * b)))$
Horizontal Hydraulic Conductivity ($K_{h_{aq}}$)	m/yr	320 to 32,000	Estimate for well sorted sands with traces of silt and gravel
Hydraulic Gradient (i)	m/m	0.03 to 0.05	Piezometric Groundwater Surface Contour Maps
Well Distance from Site (x_r)	m	100	Groundwater distance travelled from source zone to Jackson Clay Pinch-Out

Variable	Units	Value	Source
Well Vertical Distance	--	0.0	Theoretical observation well %penetration into shallow aquifer
Aquifer Temperature	°C	17.0	Estimate for probable conditions
pH	--	5.50	Estimate from field measurements
Organic Carbon Content (TOC)	--	0.0013	Laboratory Analysis

3. MULTIMED Output

Using the initial leachate concentration distribution, the receptor point 95% Upper Confidence Level (UCL) concentration for TCE was 220.0 $\mu\text{g}/\ell$. This concentration is in excess of the Maximum Contaminant Limit (MCL) of 5 $\mu\text{g}/\ell$.

Using the target leachate concentration distribution (X_{ich}), the receptor point 95% UCL concentration for TCE was approximately 5 $\mu\text{g}/\ell$. This concentration satisfies the allowable MCL requirement of 5 $\mu\text{g}/\ell$. The MULTIMED output file for the target leachate run is presented as Attachment A to this Appendix.

4. Flushing Coefficient Calculations

The flushing coefficient (F_{cal}) for soil to groundwater contaminant transport was based on a existing soil and groundwater contaminant data. F_{cal} was calculated using site-

specific geologic and hydrogeologic data coupled with existing soil and groundwater analytical data. Existing groundwater and soil contamination concentrations from source zone wells and borings were applied to the percolate volume per year, vertical hydraulic conductivity, thickness of the vadose zone, water mass balance coefficient, vadose zone porosity, and specific weight of the vadose soils to yield a site-specific flushing coefficient. Initial soil contamination levels were taken from Table 8-6 in the RI. Initial groundwater concentrations were estimated from groundwater analytical data for Monitoring Wells MW-1B, 3, 5, 9, 15, 29, 31, and 35. A groundwater data summary is presented as part of Attachment B.

F_{cal} was calculated assuming that all existing shallow groundwater contamination is the result of groundwater flushing of contaminated soils. This assumption is conservative in that it assumes no contamination reached the shallow aquifer in free phase form during the initial spill event. If such free phase contamination were to exist, actual soil flushing coefficients would be lower than calculated. Lower flushing coefficients would then yield higher allowable target concentrations for soil clean-up.

Using the data described above, the flushing coefficient for this site was calculated to be 0.0247, or about two and one half percent. Previously submitted design flushing coefficients for this site included a factor safety of about five. This safety factor was included to account for uncertainties in selected MULTIMED input parameters. However, due to conservative revisions in the multimed input and a more accurate and conservative estimate of initial shallow groundwater concentrations, this safety factor has been excluded from calculations presented in this report. A flushing coefficient calculation summary and index of formulas is provided as part of Attachment B.

5. Soil Clean-Up Level Calculations

Target levels for soil clean-up were calculated using MULTIMED output in conjunction with known site-specific geologic and hydrogeologic data. The target mean leachate concentration from the MULTIMED target level run was applied to the percolate volume per year, vertical hydraulic conductivity, thickness of the vadose zone, water mass balance coefficient, flushing coefficient, vadose zone porosity, and specific weight of the vadose soils to yield a target level for soil clean-up. Target level data is summarized in Table 4.

The MULTIMED target mean leachate concentration for this site was 33 ug/l. Data used to calculate this value is discussed in Section 2: MULTIMED Application of this Appendix.

The percolate volume per year is that volume of water which enters the vadose zone each year and is not lost to evaporation or runoff. This volume was estimated using water balance analysis taking into account temperature, precipitation, and potential evapotranspiration over a 35 year period using the Thornthwaite method. This method is conservative in that it does not fully account for the effect of vegetative evapotranspiration. Initial percolate volume calculations were based on a total site area, or 30 acres. Percolate volumes were then reduced for the smaller site area applicable to this study. Percolate volume calculations yielded a rate of approximately 145,000 cubic feet per year based on a source zone area of 6.4 acres or 20,000 square meters:

Vertical hydraulic conductivity ($K_{v_{vad}}$) through the vadose zone was estimated as one-third of the horizontal hydraulic conductivity ($K_{h_{vad}}$). This is due to the preference of water to follow horizontal rather than vertical flow paths in anisotropic soils such as silt.

The horizontal hydraulic conductivity was estimated to be 10 feet per year using tabulated values for silts and silty sands representative of the tighter vadose zone soils present at this site. This value yields a vertical hydraulic conductivity of approximately 3.3 ft/yr. Please note that previous estimates for $K_{v_{vad}}$ at this site were estimated to be one quarter of $K_{h_{vad}}$. However, a one third value is more conservative and was therefore selected for the final run.

Thickness of the vadose, or unsaturated, zone was derived from soil boring and monitoring well installation logs. The vadose zone was considered as those soils lying above the shallow groundwater surface above the Jackson Clay. Vadose zone volume was estimated as the product of the total area of the source zone, including paved areas, and the depth of the vadose zone.

The water mass balance coefficient was based on mass partitioning of solid, liquid, and vapor in the soil mass. Mass partitioning calculations are provided as part of Attachment C to this appendix.

The porosity and specific weight of the soil were estimated using tabulated values for the sandy soils encountered in the vadose zone during soil boring and monitoring well installation.

Table 4: Target Level Data

Variable	Units	Value	Source
Target Leachate Concentration (X_{lch})	mg/L	0.125	MULTIMED

Percolate Volume per Year (V_{perc})	ft ³ /yr	145000	Water balance & precipitation analysis
Vertical Hydraulic Conductivity (K_{vad})	ft/yr	3.3	$K_{vad} = (1/3) * K_{h_{vad}}$
Depth of Vadose Zone (D_{vad})	ft	50	Soil boring data
Soil Volume of Vadose Zone (V_{soil})	ft ³	6.53E+7	Site Area * D_{vad}
Water Mass Balance Coefficient (Ch_2O)	--	0.292	Mass balance analysis
Design Flushing Coefficient (F_{des})	--	0.025	Conservatively calculated value vadose zone conditions
Porosity of Vadose Zone (n)	--	0.35	Estimate for silty to clayey sands
Specific Weight of Soil	--	2.65	Estimate for silty to clayey sands

Using the above data, the theoretical target level for soil clean-up (X_{soil}) was calculated to be 533 ug/kg. A Target Levels for Soil Clean-Up summary and index of formulas is provided as part of in Attachment B to this appendix.

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ATTACHMENT A

U. S. ENVIRONMENTAL PROTECTION AGENCY

EXPOSURE ASSESSMENT

MULTIMEDIA MODEL

MULTIMED (Version 1.01, June 1991)

Run options

CARRIER COLLIERVILLE

Chemical simulated is TCE

Option Chosen Saturated zone model
 Run was MONTE
 Infiltration input by user
 Number of monte carlo simulations 200
 Run was steady-state
 Reject runs if Y coordinate outside plume
 Do not reject runs if Z coordinate outside plume
 Gaussian source used in saturated zone model

CHEMICAL SPECIFIC VARIABLES

VARIABLE NAME	UNITS	DISTRIBUTION	PARAMETERS		LIMITS	
			MEAN	STD DEV	MIN	MAX
Solid phase decay coefficient	1/yr	CONSTANT	0.000E+00	-999.	0.000E+00	0.100E+11
Dissolved phase decay coefficient	1/yr	CONSTANT	0.000E+00	-999.	0.000E+00	0.100E+11
Overall chemical decay coefficient	1/yr	CONSTANT	0.000E+00	-999.	0.000E+00	0.100E+11
Acid catalyzed hydrolysis rate	l/M-yr	CONSTANT	0.000E+00	-999.	0.000E+00	-999.
Neutral hydrolysis rate constant	1/yr	CONSTANT	0.000E+00	-999.	0.000E+00	-999.
Base catalyzed hydrolysis rate	l/M-yr	CONSTANT	0.000E+00	-999.	0.000E+00	-999.
Reference temperature	C	CONSTANT	25.0	-999.	0.000E+00	100.
Normalized distribution coefficient	ml/g	CONSTANT	0.126E+09	-999.	0.000E+00	-999.
Distribution coefficient	--	DERIVED	-999.	-999.	0.000E+00	0.100E+11
Biodegradation coefficient (sat. zone)	1/yr	CONSTANT	0.000E+00	-999.	0.000E+00	-999.
Air diffusion coefficient	cm ² /s	CONSTANT	0.000E+00	-999.	0.000E+00	10.0
Reference temperature for air diffusion	C	CONSTANT	25.0	-999.	0.000E+00	100.
Molecular weight	g/M	CONSTANT	131.	-999.	0.000E+00	-999.
Mole fraction of solute	--	CONSTANT	0.123E-05	-999.	0.100E-08	1.00
Vapor pressure of solute	mm Hg	CONSTANT	74.0	-999.	0.000E+00	100.
Henry's law constant	atm-m ³ /M	CONSTANT	0.110E-01	-999.	0.100E-09	1.00
Overall 1st order decay sat. zone	1/yr	DERIVED	0.000E+00	0.000E+00	0.000E+00	1.00
Not currently used		CONSTANT	-999.	-999.	0.000E+00	1.00
Not currently used		CONSTANT	-999.	-999.	0.000E+00	1.00

SOURCE SPECIFIC VARIABLES

VARIABLE NAME	UNITS	DISTRIBUTION	PARAMETERS		LIMITS	
			MEAN	STD DEV	MIN	MAX
Infiltration rate	m/yr	UNIFORM	0.450	-999.	0.157	0.450
Area of waste disposal unit	m ²	CONSTANT	0.200E+05	-999.	0.100E-01	-999.
Duration of pulse	yr	CONSTANT	-999.	-999.	0.100E-08	-999.
Spread of contaminant source	m	DERIVED	33.3	-999.	0.100E-08	0.100E+11
Recharge rate	m/yr	CONSTANT	0.000E+00	-999.	0.000E+00	0.100E+11
Source decay constant	1/yr	CONSTANT	0.000E+00	-999.	0.000E+00	-999.
Initial concentration at landfill	mg/l	NORMAL	0.330E-01	0.760E-01	0.500E-02	0.240
Length scale of facility	m	DERIVED	200.	-999.	0.100E-08	0.100E+11
Width scale of facility	m	DERIVED	200.	-999.	0.100E-08	0.100E+11
Near field dilution		DERIVED	1.00	0.000E+00	0.000E+00	1.00

AQUIFER SPECIFIC VARIABLES

VARIABLE NAME	UNITS	DISTRIBUTION	PARAMETERS		LIMITS	
			MEAN	STD DEV	MIN	MAX
Particle diameter	cm	CONSTANT	0.500E-01	-999.	0.100E-08	100.
Aquifer porosity	--	CONSTANT	0.350	-999.	0.100E-08	0.990
Bulk density	g/cc	CONSTANT	1.86	-999.	0.100E-01	5.00
Aquifer thickness	m	CONSTANT	1.00	-999.	0.100E-08	0.100E+06
Source thickness (mixing zone depth)	m	CONSTANT	1.00	-999.	0.100E-08	0.100E+06
Conductivity (hydraulic)	m/yr	UNIFORM	0.320E+04	-999.	320.	0.320E+05
Gradient (hydraulic)		UNIFORM	0.300E-01	-999.	0.300	0.500
Groundwater seepage velocity	m/yr	DERIVED	-999.	-999.	0.100E-09	0.100E+09
Retardation coefficient	--	DERIVED	-999.	-999.	1.00	0.100E+09
Longitudinal dispersivity	m	FUNCTION OF X	-999.	-999.	-999.	-999.
Transverse dispersivity	m	FUNCTION OF X	-999.	-999.	-999.	-999.
Vertical dispersivity	m	FUNCTION OF X	1.00	-999.	-999.	-999.
Temperature of aquifer	C	CONSTANT	17.0	-999.	0.000E+00	100.
pH	--	CONSTANT	5.50	-999.	0.300	14.0
Organic carbon content (fraction)		CONSTANT	0.130E-02	-999.	0.100E-05	1.00
Well distance from site	m	CONSTANT	100.	-999.	1.00	-999.
Angle off center	degree	CONSTANT	0.000E+00	-999.	0.000E+00	360.
Well vertical distance	m	CONSTANT	0.000E+00	-999.	0.000E+00	1.00

0 Values generated which exceeded the specified bounds.

----- RESULTS -----

SATURATED ZONE TRANSPORT
CARRIER COLLIERVILLE - LEE THOMAS RESPONSE RUN

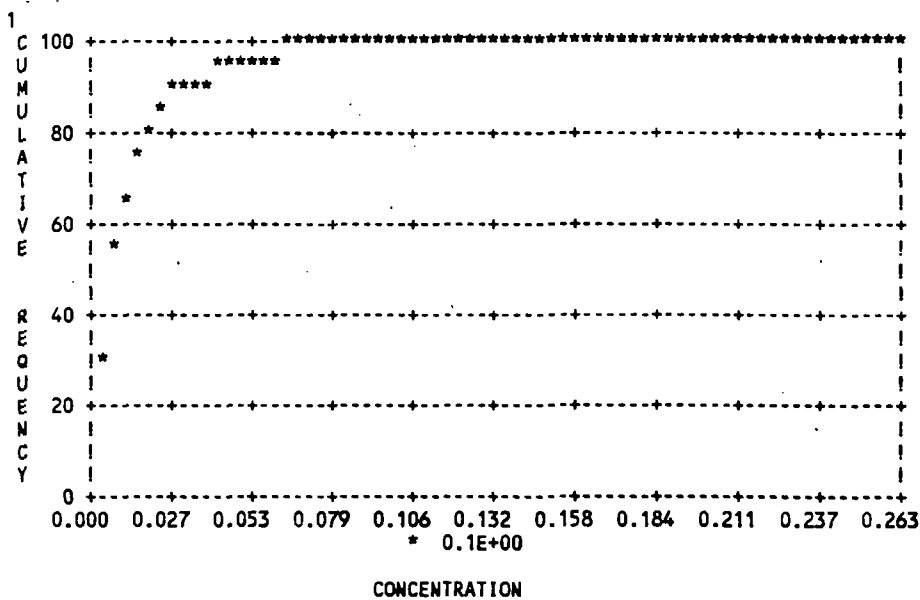
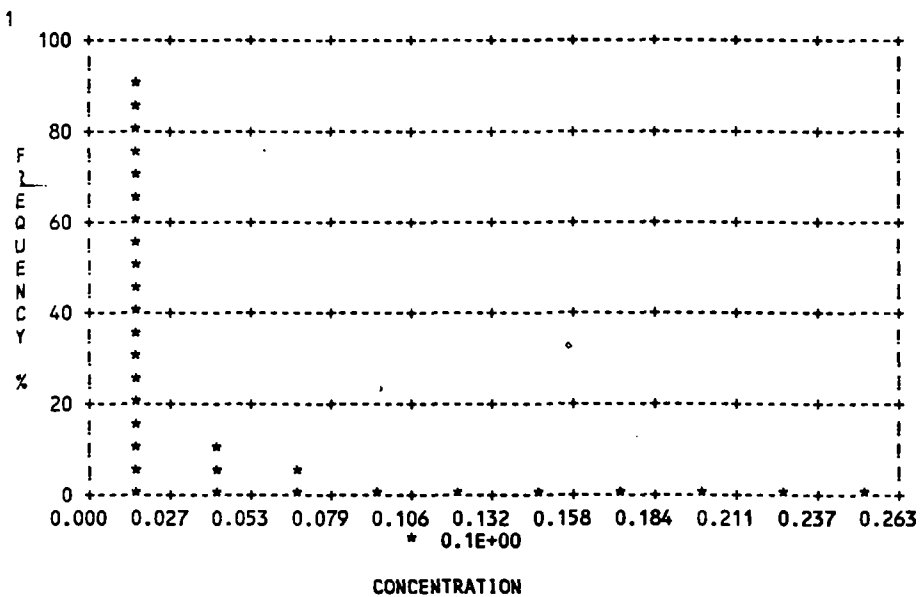
CASE

95. PERCENT CONFIDENCE INTERVAL

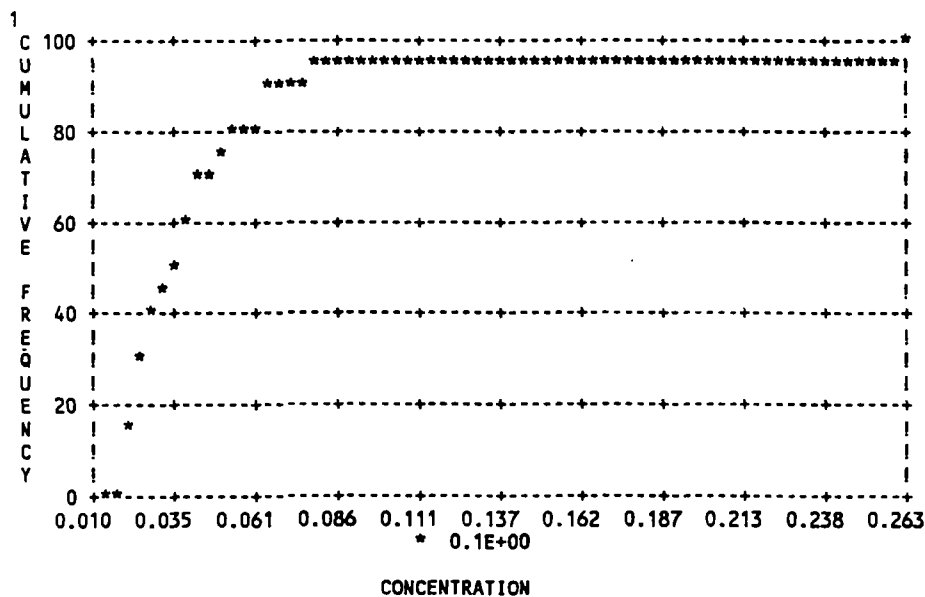
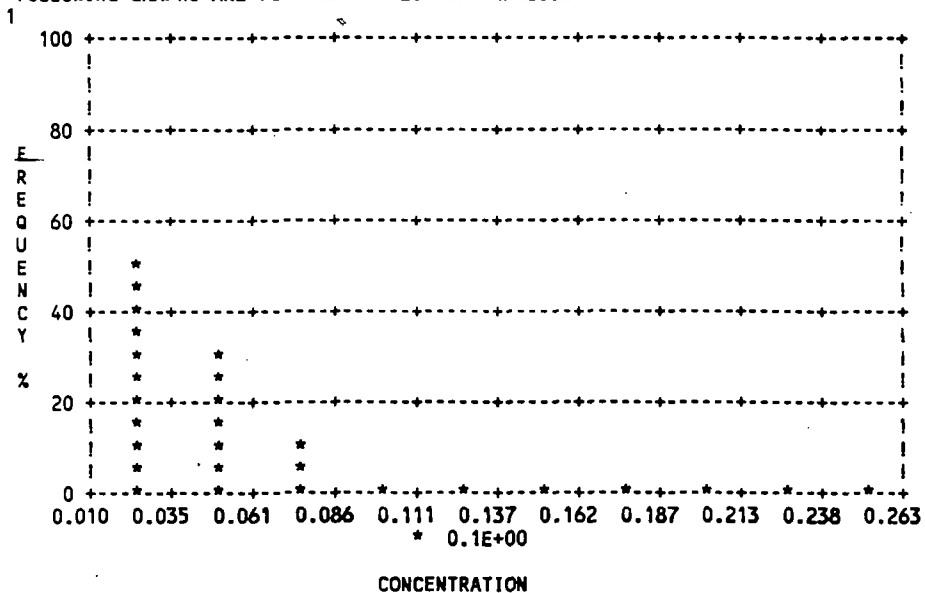
N	=	200		
MEAN	=	0.141E-02		
STANDARD DEVIATION	=	0.245E-02		
COEFFICIENT OF VARIATION	=	1.74		
MINIMUM VALUE	=	0.444E-04		
MAXIMUM VALUE	=	0.263E-01		
50th PERCENTILE	=	0.685E-03	0.603E-03	0.790E-03
80th PERCENTILE	=	0.181E-02	0.143E-02	0.241E-02
85th PERCENTILE	=	0.225E-02	0.181E-02	0.318E-02
90th PERCENTILE	=	0.337E-02	0.241E-02	0.429E-02
95th PERCENTILE	=	0.502E-02	0.385E-02	0.737E-02

-999 UNABLE TO COMPUTE CONFIDENCE BOUND DUE TO INSUFFICIENT DATA

VALUE	% OF TIME EQUALLED OR EXCEEDED	% OF TIME IN INTERVAL
0.444E-04	100.000	
		88.000
0.267E-02	12.000	
		8.000
0.530E-02	4.000	
		3.000
0.793E-02	1.000	
		0.000
0.106E-01	1.000	
		0.000
0.132E-01	1.000	
		0.500
0.158E-01	0.500	
		0.000
0.184E-01	0.500	
		0.000
0.211E-01	0.500	
		0.000
0.237E-01	0.500	
		0.000
0.263E-01	0.500	



FOLLOWING GRAPHS ARE FOR THE TOP 20% OF THE RESULTS



ATTACHMENT B

CARRIER SHALLOW GROUNDWATER DATA
(SOURCE ZONE WELLS)

ATA SUMMARY

MW#	CONC (PPB)	MW#	CONC (PPB)	MW#	CONC (PPB)	MW#	CONC (PPB)	MW	CONC (PPB)	MW	CONC (PPB)	MW#	CONC (PPB)	MW#	CONC (PPB)
1B	220	3	2400	5	260	9	20	15	38000	29	0	31	288	35	0
	390		3400		1200		30		150000		0		55		0
	380		2500		1900				120000						
	305		1800		4800				59000						
	300		4100		3200				940						
	330		1600		3100				19000						
	620		2800		2200				55000						
	490		5200		9000				20000						
	790		3300		4500				120000						
	820		3100		6500				5900						
	340		2500		8200				64000						
	500		8000		4200				140000						
	420		2600		4700										
	760		1300		1500										
	440		5400		760										
	440		2900		7500										
	77		5000		4600										
	130		6000		5600										
	310		6200		11000										
	320		7800		4400										
	490		5000		7300										
	940														
	1100														
	580														
	760														
	850														

AVERAGED DATA SUMMARY

MW#	CONC (PPB)		
1B	504		
3	3948		
5	4591		
9	25		
15	65987		
29	0		
31	172		
35	0		
AVG	9403	=	9.4 PPM

FLUSHING COEFFICIENT CALCULATION SUMMARY

fln: MULTTTAR.WQ1

KNOWN DATA

ENTER
VALUE
UNITS
!!!!

Xlch	= INITIAL LEACHATE CONCENTRATION	9.40E+00	mg/l
Xsoil(init)	= INITIAL SOIL CONCENTRATION	1.52E+02	mg/kg
Vperc'	= PERCOLATE VOLUME PER YEAR	1.45E+05	ft^3/yr
Kvad	= VERTICAL HYDRAULIC CONDUCTIVITY	3.30E+00	ft/yr
Dvad	= THICKNESS OF VADOSE ZONE	5.00E+01	ft
Vsoil	= VADOSE ZONE SOIL VOLUME	6.53E+07	ft^3
Ch2o	= WATER MASS BALANCE COEFFICIENT	2.92E-01	DIMENSIONLESS
n	= POROSITY OF VADOSE ZONE	3.50E-01	DIMENSIONLESS
g	= SPECIFIC WEIGHT OF SOIL	2.65E+00	g/ml

CALCULATED RESULTS

Vperc'	= PERCOLATE VOLUME PER YEAR	4.11E+06	l/yr
Tperc	= PERCOLATE RETENTION TIME	1.52E+01	yr
Vperc	= PERCOLATE RETENTION VOLUME	6.22E+07	l
Vsoil	= VADOSE ZONE SOIL VOLUME	1.85E+09	l
Mconperc	= MASS OF CONTAMINANT IN PERCOLATE	5.85E+08	mg
Mconsoil	= MASS OF CONTAMINANT IN SOIL	4.85E+11	mg
Msoil	= MASS OF SOIL IN VADOSE ZONE	3.19E+09	kg
Fcal	= CALCULATED FLUSHING COEFFICIENT	4.14E-03	DIMENSIONLESS

INDEX OF FORMULAS

Tperc	=	$\frac{Dvad}{Kvad}$	Fcal	=	$\frac{Mconperc}{Ch2o * Mconsoil}$
Vperc	=	Tperc * Vperc'	Msoil	=	Vsoil * g * (1 - n)
Mconperc	=	Xlch * Vperc	Mconsoil	=	Msoil * Xsoil

NOTE: * INITIAL LEACHATE CONC. F/AUGUST, 1991, GW ANALYTICAL DATA FOR WELLS SCREENED NEAR THE JACKSON CLAY SURFACE WITHIN THE SOURCE ZONE.
* EXISTING SOIL CONCENTRATION (MEAN) FROM TABLE 8-6, REMEDIAL INVESTIGATION, JUNE, 1991

TARGET LEVELS FOR SOIL CLEAN-UP

fln: MULTITAR.WQ1

KNOWN DATA		ENTER VALUE !!!!	UNITS
Xlch	= ALLOWABLE LEACHATE CONCENTRATION	3.30E-02	mg/L
Vperc'	= PERCOLATE VOLUME PER YEAR	1.45E+05	ft ^ 3/yr
Kvad	= VERTICAL HYDRAULIC CONDUCTIVITY	3.30E+00	ft/yr
Dvad	= THICKNESS OF VADOSE ZONE	5.00E+01	ft
Vsoil	= VADOSE ZONE SOIL VOLUME	6.53E+07	ft ^ 3
Ch2o	= WATER MASS BALANCE COEFFICIENT	2.92E-01	DIMENSIONLESS
Fcal	= CALCULATED FLUSHING COEFFICIENT	4.14E-03	DIMENSIONLESS
n	= POROSITY OF VADOSE ZONE	3.50E-01	DIMENSIONLESS
g	= SPECIFIC WEIGHT OF SOIL	2.65E+00	g/ml

CALCULATED RESULTS

Vperc'	= PERCOLATE VOLUME PER YEAR	4.11E+06	L/yr
Vsoil	= VADOSE ZONE SOIL VOLUME	1.85E+09	L
Tperc	= PERCOLATE RETENTION TIME	1.52E+01	yr
Vperc	= PERCOLATE RETENTION VOLUME	6.22E+07	L
Mconperc	= MASS OF CONTAMINANT IN PERCOLATE	2.05E+06	mg
Mconsoil	= MASS OF CONTAMINANT IN SOIL	1.70E+09	mg
Msoil	= MASS OF SOIL IN VADOSE ZONE	3.19E+09	kg
Xsoil	= TARGET LEVEL FOR SOIL CLEAN-UP	5.33E-01	mg/kg
	= TARGET LEVEL FOR SOIL CLEAN-UP	533	ppb

INDEX OF FORMULAS

Tperc	=	$\frac{Dvad}{Kvad}$	Mconsoil	=	$\frac{Mconperc}{Ch2o * Fdgn}$
Vperc	=	Tperc * Vperc'	Msoil	=	Vsoil * g * (1 - n)
Mconperc	=	Xlch * Vperc	Xsoil	=	$\frac{Mconsoil (mg)}{Msoil (kg)}$

ATTACHMENT C

Memphis Sands Aquifer Characteristics

Transmissivity (gpd/ft)	= 242,500
Storage Coefficient	= 0.001 to 0.0001
Vertical Hydraulic Conductivity of Jackson Clay Aquitard	= 0.03-0.62 gpm
Horizontal Hydraulic Conductivity of Memphis Sands Aquifer	= 1,212.5 gpd/ft

Contaminant Distribution (Mass Partitioning)

In Vadose Zone Soils

In order to determine the distribution of contaminants in the soil medium, formulae were obtained from USEPA's Determining Soil Response Actin Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples, Document Number EPA/540/2-89/057, October 1989. The required calculations are as follows:

$$C_t = (\gamma_s * C_s) + (\theta * C_l) + (a * C_g)$$

Where: C_t	= Total Contaminant Fraction	= 1.0
γ_s	= Bulk Density of Soil (g/cm ³)	= 2.65 * (1 - porosity)
C_s	= Solid Phase Contaminant Constant	
θ	= Moisture Content of Soil (volume fraction)	= 0.15
C_l	= Liquid Phase Contaminant Constant	
a	= Air Content of Soil (volume fraction)	= 0.15
C_g	= Gas Phase Contaminant Constant	

$$C_s = K_H * C_l$$

$$C_g = K_d * C_l$$

Where:	K_H	= Assumed @ 0.4 (from Stamina Mills RI for TCE.)	
	K_d	= Normalized Distribution Coefficient	= $K_{oc} * TOC$
	K_{oc}	= Distribution Coefficient for Trichloroethylene	
	TOC	= Total Organic Carbon Fraction	= 0.0013

Contaminant Distribution Calculations (Mass Partitioning)

Vapor Partitioning Coefficient (C_{vapor}):

$$\begin{aligned} a * C_g / C_t &= a * K_H / [\gamma_s * K_d + \theta + a * K_H] \\ &= (0.15)(0.4) / [1.85(0.164) + 0.15 + (0.15)(0.4)] \\ &= (0.06) / [0.303 + 0.15 + 0.06] \\ &= 0.117 \end{aligned}$$

Solid Partitioning Coefficient (C_{solid}):

$$\begin{aligned} b * C_s / C_t &= \gamma_s * K_d / [\gamma_s * K_d + \theta + a * K_H] \\ &= (1.85)(0.164) / [(1.85)(0.164) + 0.15 + (0.15)(0.4)] \\ &= (0.303) / [0.303 + 0.15 + 0.06] \\ &= 0.591 \end{aligned}$$

Water Partitioning Coefficient ($C_{\text{H}_2\text{O}}$):

$$\begin{aligned} c * C_l / C_t &= 1 - (0.117 + 0.591) \\ &= 0.292 \end{aligned}$$

Note: Calculations assume 30% bulk soil porosity in Terrace Deposits; 70% solids; 50% interstitial saturation.

From these calculations, it can be determined that nearly 30% of soil TCE is present in the soil-bound water phase. This information is useful as contaminant transport in soils (at or near saturation) is dependent upon the movement of contaminants in the aqueous phase. Therefore, the determination of the portion of contaminant present in soil moisture facilitates the calculation of contaminant flushing efficiency, and in turn, the rate of contaminant transfer to other media (i.e. groundwater).

Thornthwaite Equation

The Thornthwaite equation may be used to calculate PET on the basis of average monthly temperature as follows:

$$\begin{aligned}i &= (T/5)^{1.514} = \text{monthly heat index} \\I &= \sum i = \text{heat index} \\a &= 0.49 + (0.0179 * I) - (0.0000771 * I^2) + (0.000000675 * I^3) \\E_p &= 1.6 [(10 * T_p) / I]^a \\E_p &= \text{Potential Evapotranspiration (PET)} \\T_p &= \text{Temperature } ^\circ\text{C}\end{aligned}$$

Note: The Thornthwaite Equation is generally conservative in that it yields under estimated values for PET.

Thornthwaite Applications

$$\begin{aligned}I &= 1.185 + 1.551 + 3.219 + 6.049 + 8.917 + 11.926 + 13.04 + 12.688 + \\&\quad 10.189 + 6.548 + 1.837 + 1.448 \\&= 78.60 \\a &= 0.49 + 1.407 - 0.476 + 0.328 \\&= 1.749\end{aligned}$$

The average monthly temperature values used to compute monthly heat indexes (i) were obtained from the Shelby County Soil Survey. Using this temperature data, PET for each month of the year was computed and is summarized below in Table 1.

TABLE 1 MONTHLY PET VALUES												
	J	F	M	A	M	J	J	A	S	O	N	D
E _t cm	0.9	1.2	2.8	5.9	9.3	13.1	14.5	14.0	10.9	6.5	1.5	1.1
E _t mm	8.8	12.1	28.3	59.1	93.0	131	145	140	109	64.9	14.7	11

These PET values may be used in conjunction with precipitation and soil data to compute annual an percolate volume. This is accomplished through application of the water balance method. The water balance for the Collierville NPL Site is shown in Table 2.

Water Balance Assumptions

Cr/o	=	Coefficient of Runoff	=	0.45
ST	=	Soil Moisture Storage	=	150 mm available water based on loamy silt surface soils. Residual moisture (May through October) obtained from tabulated values)
AET	=	Actual Evapotranspiration	=	PET if AST is positive or 0
	=		=	PET + [(I - PET) - AST] if AST is negative.
PERC	=	Percolation Rate	=	I - AET if ST = 150 mm
	=		=	I - AET - AST during soil recharge (November through January)

TABLE 2
COLLIERVILLE NPL SITE
WATER BALANCE TABLE

Parameter	J	F	M	A	M	J	J	A	S	O	N	D	
PET mm/mo.	9	12	28	59	93	131	145	140	109	65	15	11	
P ^A mm/mo.	154	119	129	118	107	93	90	75	72	69	111	125	
C _{RO}	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	
R/O mm/mo.	69	54	58	53	48	42	41	34	32	31	50	56	
I P-R/O	85	65	71	65	59	51	50	41	40	38	61	69	
I-PET	+76	+53	+43	+6	-34	-80	-95	-99	-69	-27	+46	+58	
ΣNEG 1-PET				(0)	-34	-114	-209	-308	-377	-404			
ST mm	150	150	150	150	119	69	36	18	12	10	56	114	
Δ ST	+36	0	0	0	-31	-50	-33	-18	-6	-2	+46	+58	
AET mm/mo.	9	12	28	59	90	101	83	59	46	40	15	11	
PERC. mm/mo.	40	53	43	6	0	0	0	0	0	0	0	0	142 mm/yr

Notes:

PET = Potential Evapotranspiration

P = Precipitation

C_{RO} = Coefficient of Runoff

R/O = Runoff

(From Thornthwaite Equation)

I = Infiltration

ST = Soil Moisture Storage for Loamy Soil (150 mm available H₂O)

AET = Actual Evapotranspiration

PERC = Percolate

^A - from USDA/SCS Shelby County Soil Survey - Precipitation Records 1931-1960